22 April, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

It was resolved—That Messrs. J. V. W. Amor, G. E. W. Cruttwell, F. Hudleston, E. L. Mansergh, A. H. Preece, R. J. G. Read, J. J. Webster and L. S. Zachariasen be appointed to act as Scrutineers, in accordance with the By-laws, of the Ballot for the election of the Council for the year 1902–1903.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

HARRY HERBERT LAKE.
PERCY ARCHIBALD LOW.
WILLIAM LUNN.
HARRY POWELL MILES.
ARTHUR MUSKER.
CHARLES HENRY PRIESTLEY.
HERBERT FREDERICK TOMALIN.
JOHN HENRY WHIELDON.

And that the following Candidates had been admitted as

Students.

JOHN JOSEPH MURPHY.
ALAN OCTAVIUS WHITEHEAD.

The Candidates balloted for and duly elected were: as

A Member.

GEORGE DEUCHARS.

Associate Members.

VERNON COOPER, Stud. Inst. C.E.
JAMES CHARLES HERBERT CROSLAND, Stud. Inst. C.E.
RICHARD LAWSON LAFFÈRE, B.A.I. (*Dubl.*)
EDWARD NATHANIEL PEARCE.
CHARLES EDWARD SHACKLE.

(*Paper No. 3346.*)

"Locomotive Fire-box Stays."

By FRANCIS WILLIAM WEBB, Vice-President Inst. C.E.

IN view of the large amount of attention which locomotive engineers at home and abroad have given in recent years to the question of the most suitable material for the staying of locomotive fire-

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

boxes, chiefly owing to increased boiler-pressures, the Author's experience in this direction, together with the results of an investigation made by him on the subject, may be of interest, especially to those concerned in the construction of locomotives.

At the present time the London and North Western Railway Company have 3,000 locomotives, with boiler-pressures varying between 120 lbs. and 200 lbs. per square inch. With ten exceptions of a special design, all the boilers are fitted with copper fire-box stays, varying in diameter between $\frac{15}{16}$ inch and $1\frac{1}{16}$ inch. In accordance with the experience of most locomotive engineers, it has been found necessary to renew a number of stays from time to time, owing either to wastage of the heads, to leakage or to breakage. Wastage occurs principally in the vicinity of the brick arch: breakages occur chiefly at the right and left-hand front top corners, in a direction more or less diagonal across the plates. Sometimes the stays break in a similar diagonal direction, but commencing at the back top corners of the side plates. As is well known, these breakages are chiefly due to the expansion and contraction of the inner copper casing of the box. Photographs of two typical fractures of stays are given in Figs. 1, Plate 4. Breakage of the stays in the lower part of the box—which is not frequent—is invariably due to the stays being thickly coated with boiler-scale, and consequently becoming over-heated.

From time to time various alloys have been offered as substitutes for copper, owing to their possessing a greater tensile strength. In the hope of obtaining a material superior to copper, some of these have been tried practically; and this Paper records the results of such trials and of the Author's recent experience with copper stays.

Copper.

Under this head is given the Author's experience as far as it relates to the use of copper stays in the boilers of the latest fifty four-cylinder compound express passenger engines on the London and North Western Railway, all of which work at a steam-pressure of 200 lbs. per square inch. The foremen have strict instructions that all leaky stays, or stays with wasted heads, are to be replaced at once; and, further, that the boilers are to be often and well washed out.

In June, 1897, the first of the forty four-cylinder compound express passenger engines of the "Diamond Jubilee" class commenced to run, having a boiler-pressure of 200 lbs. per square inch, and the fire-boxes stayed with $1\frac{1}{16}$-inch copper stays; and up to

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

the 31st December, 1901, the aggregate mileage for these engines was 5,622,064 miles. The total number of copper stays replaced during that period was 6,663, or one stay per 844 miles. None of the stays replaced are recorded as broken, although no doubt some few were, but not sufficiently so to require a special entry. Wasted heads and leakage are given as the reasons for replacement.

One stay per 844 miles may appear at first sight to be rather a large percentage; but, as each boiler contains 996 copper stays, the engine would have to run a distance of 840,500 miles before all the stays (or a number equal to all) would be replaced; which, it must be admitted, compares favourably with the renewal of other parts of the engine for such a distance. Further, these engines are worked very hard, the average speed being 50 miles per hour, hauling a load of 350 tons to 400 tons, including engine and tender; and many of them run 158 miles in 3 hours and 10 minutes without a stop, consuming coal at the rate of 1 ton per hour.

In June, 1901, the first of the ten four-cylinder compound express passenger engines of the "Alfred the Great" class commenced to run, having a boiler-pressure of 200 lbs. per square inch, and the fire-box stayed with 1,032 copper stays $1\frac{1}{16}$ inch in diameter; and up to the 31st December last the aggregate mileage covered by these engines was 277,800 miles (greatest mileage, 43,000; least, 17,000); but no copper stays had to be replaced during that period.

Without discussing here the merits or demerits of copper for the stays of these high-pressure boilers, it has, in the Author's opinion, answered satisfactorily.

Copper-Zinc Alloy (40 per cent. of Zinc).

In 1897 the fire-box of a passenger engine (boiler-pressure 150 lbs. per square inch) was stayed with 1-inch stays of a special copper-zinc alloy manufactured for the purpose. Each stay was riveted in accordance with the usual practice with copper. The engine commenced to run in April, 1898. After running 82,020 miles (up to September, 1899), twelve stays were replaced by copper, owing to leakage, and one hundred and thirty-three others were drilled and drifted; after a further mileage of 72,713 miles, fifteen more were replaced by copper, and all the remainder were fullered in December, 1900. In January, 1901, all the stays were re-riveted; and in April, 1901, owing to their leaking so badly as to render the boiler unsafe for working, it was decided to replace all the copper-zinc stays with copper stays, the total mileage

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

for the boiler being 169,058 miles. As the fire-box contained 646 stays, the life of this copper-zinc alloy is equal to only 262 miles per stay, at a boiler-pressure of only 150 lbs. per square inch.

The material not having given the satisfaction claimed for it, a number of the stays were removed from each side of the box, care being taken not to damage the threads in the copper plate; in fact, after being drilled from the shell-plate, they came away from the copper plate with a very slight blow, indicating that they were held in position only by the scale surrounding them. On examination of their heads and threads it was observed that they were much wasted. The surface of the threads was still coated with scale, proving that they had not been damaged in removal.

Three stays from each plate, selected at random, were cut in two longitudinally, and one half of each was polished and etched. Fig. 2, Plate 4, is a full-size view of one of them, as removed from the box. It shows the extent to which the wastage has taken place, and is representative of the twelve. The significant feature, however, is that cracks are seen in them all, running from the bases of a number of threads towards the head, at an angle of about 45°. Figs. 3 and 4 show the longest and the shortest cracks, magnified four diameters. It will be observed also that the threads are badly wasted, which accounts for the excessive leakage of the boiler.

With a view to ascertain the uniformity or otherwise of the chemical composition of the stays, separate samples marked C, E, and H (Fig. 2) were taken from the centre and the edge of the body of the stay, and from the surface of the head, the analyses of which are as follows:—

ANALYSES OF COPPER-ZINC ALLOY.

Element.	Sample from Centre.	Sample from Edge.	Mean of Centre and Edge.	Sample from surface of Head.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Copper	60·21	60·25	60·23	61·05
Zinc	39·55	39·66	39·61	38·84
Iron	0·32	0·25	0·28	0·23
Manganese	0·04	0·02	0·03	0·04
Arsenic	0·096	0·096	0·096	0·096
Antimony	0·012	0·012	0·012	0·012
Lead	Trace	Trace	Trace	Trace
Phosphorus	Trace	Trace	Trace	Trace
	100·228	100·288	100·258	100·268

Ratio of copper to zinc, *1·52 : 1* (analysis).

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

From these results it is evident that the stays have not lost zinc by contact with the water of the boiler; there is, however, a slight loss of zinc from the surface of the head.

The holes in the heads of the stays were partly filled with a black deposit; some of this was scraped out, care being taken not to touch the metal of the stay, and the copper and zinc in it were estimated, showing copper 5·75 per cent., zinc 2·68 per cent., and ratio of copper to zinc 2·14 : 1. The deposit was then removed entirely from some of the holes, revealing a surface distinctly coppery in appearance. This points to slight wastage at the heads of the stays, due to loss of zinc by volatilization owing to the high temperature of the box, but not sufficient, in the Author's opinion, to warrant the statement that the alloy has suffered loss of zinc.

Copper-Zinc Alloy (9 per cent. of Zinc).

In September, 1891, the fire-box of a six-wheel-coupled coal-engine (boiler-pressure 150 lbs. per square inch) was fitted with 1-inch stays of this alloy, riveted in the usual way. Between that date and the 31st December, 1901, fifty-one stays were replaced by copper; fourteen of them had broken, and the remaining thirty-seven were removed owing to wasted heads and leakage. The total mileage was 284,978 miles, equivalent to one stay replaced per 5,588 miles.

The chemical analysis of the alloy is as follows:—

	Per Cent.
Copper	89·75
Zinc	9·09
Tin	0·76
Lead	0·08
Phosphorus	0·03
Iron	Traces.
Manganese	
Arsenic	
Carbon	
	99·71

The tensile test at the ordinary temperature gave a breaking-weight of 20 tons per square inch; elongation 55 per cent. on a length of 2 inches; contraction of area 64 per cent. The average of seven similar engines stayed with 1-inch copper stays, working the same kind of traffic between 1891 and December, 1901, gives one stay renewed per 1,805 miles. Thus the results of the 9-per cent. zinc alloy compared with copper are highly satisfactory. Unfortunately none of the material remained after staying the boiler, so

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

that the alloy could not be included in the investigation referred to later.

Copper-Tin Alloy (3 per cent. of Tin).

In 1897 the fire-box of an express goods engine (six wheels coupled; boiler-pressure 150 lbs. per square inch) was fitted with 1-inch stays of a special copper-tin alloy, the usual practice of riveting being adhered to. The engine commenced to run in July, 1897. After running 93,290 miles (up to March, 1901) one hundred and forty-five stays were removed, owing to their being loose in the holes and having wasted heads; but none of them were broken. Up to the 31st December, 1901, the engine has not required further repairs, the total mileage being 113,657 miles, or one stay renewed per 791 miles. Four other boilers have been stayed with the same alloy, but have not been running long enough to afford any basis for comparison.

Copper-Aluminium Alloy.

The merits of copper-aluminium alloys have often been proclaimed; and results of mechanical tests at ordinary and at steam temperatures having been given to show their suitability for positions in which the metal is subject to heat and stress combined, the Author decided in August, 1900, to make a trial of a $7\frac{1}{4}$-per cent. aluminium alloy for fire-box stays. The figures submitted with a sample rod, and the results of the tests thereof by the London and North Western Railway, are as follows:—

	Temperature of Test. Fahr.	Breaking Weight per Square Inch.	Elongation, on Length of 2 Inches.	Contraction of Area.	Remark.
	Degrees.	Tons.	Per Cent.	Per Cent.	
Maker's tests . .	60	27·5	80·0	..	
	374	24·7	80·0	..	
London and North Western Railway test	60	25·9	89·0	70·1	Good sound fracture.
Cold bending test .	Bent close upon itself without signs of cracking.				

The fire-box of an express goods engine (six wheels coupled, boiler-pressure 150 lbs. per square inch) was stayed with 1-inch stays of this alloy, riveted in the Company's usual way. The engine commenced to run in January, 1901, but had to be taken

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

off the line after being in use only 2 months and running 2,400 miles, owing to a number of stays being broken—some in the copper plate, some in the steel plate: a number of others had the heads broken clean away, thus causing the copper plates to bulge.

The fractured ends of the stays were not uniform in appearance, some having broken off very irregularly with large crystalline faces, while others were more regular in fracture and presented smaller crystals. Several of them were sectioned longitudinally, polished and etched. Fig. 5, Plate 4, is a full-size view of a stay which broke at both ends. Figs. 6, 7, and 8 show the structure of stays which are typical of all those examined. Fig. 9 is a photo graph showing the fracture of a broken head. A large crystalline structure does not explain the breakages; for out of eighteen stays, the ends of which were examined, twelve showed the more regular fracture, and consequently the comparatively small crystalline structure, exemplified by Fig. 6.

Chemical analysis of the stays showed that commercially pure copper and aluminium had been employed in the manufacture of the alloy, and no injurious elements were present to account for their failure:—

	Per Cent.
Copper	93·18
Aluminium	6·88
Phosphorus	Mere trace
	100·06

The average tensile strength of four broken stays at the ordinary temperature was 25·3 tons per square inch.

MILD STEEL (BESSEMER).

Steel stays have been well tried, both solid for riveting and drilled for drifting; but, owing to the well-known difficulty of keeping a steam-tight joint in the copper plate, their use in copper fire-boxes has been abandoned. Particulars of a passenger engine (boiler-pressure 150 lbs. per square inch), fitted with steel stays, may, however, be of interest. The engine was put in use in January, 1889; in January, 1892, two hundred and eighty-seven stays were replaced by copper ones. In July, 1897, a further two hundred and thirty-nine were replaced by copper, and in June, 1899, thirty-two more were so replaced. In 1901 the boiler was scrapped. Total mileage 340,839.

An alloy of copper and manganese, containing 4 per cent. of

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

manganese, has been offered to the Author, but up to the present time it has not been given a trial. However, from a report[1] of a practical trial of such an alloy for high-pressure locomotives, made by Mr. du Bousquet, of the Northern Railway of France, it appears to answer satisfactorily.

From this account of trials in practice of the above-mentioned substitutes for copper, it will be admitted that none of them, all things considered, show any improvement on copper, except perhaps the copper-zinc (9 per cent. zinc) alloy. The chief recommendation of each of them has been its greater strength compared with copper; but evidently increased strength is not all that is required, seeing that the broken copper-aluminium stays gave 25·3 tons per square inch, with an elongation superior to copper: yet no one would knowingly use an alloy with such a distinctly crystalline structure as that indicated by Figs. 7 and 8, Plate 4.

Owing to the failure of the copper-zinc alloy (40 per cent. zinc) and the complete failure of the copper-aluminium alloy, the Author arranged to have the matter investigated more closely.

Investigation as to the Comparative Suitability of Copper and Copper Alloys for Fire-box Stays.

The physical condition of alloys generally at various temperatures has recently received the careful attention of many scientific men, particularly in this country of Sir William Roberts-Austen, K.C.B., Hon. M. Inst. C.E., who has determined the tenacity of various alloys at temperatures up to 900° F., showing in some instances a loss of 85 per cent. in strength.[2]

From published results it would appear to be the usual practice of engineers to test fire-box stays at a temperature corresponding with the steam-pressure at which they are intended to be worked. It has been pointed out,[3] however, by Mr. Le Chatelier that the copper plates of locomotive fire-boxes may attain a temperature of 750° F.; and Mr. T. Hurry Riches, M. Inst. C.E., considers[4] that a temperature of 800° F. may exist at the surface of the stay-heads, and that a mean temperature of 600° F. is not improbable at a distance of ½ inch from the heads.

In order to ascertain the temperature which fire-box stays may attain, the Author fitted a stationary boiler of the standard loco-

[1] *Revue générale des Chemins de Fer*, March 1901, p. 248. See also *post*, p. 126.

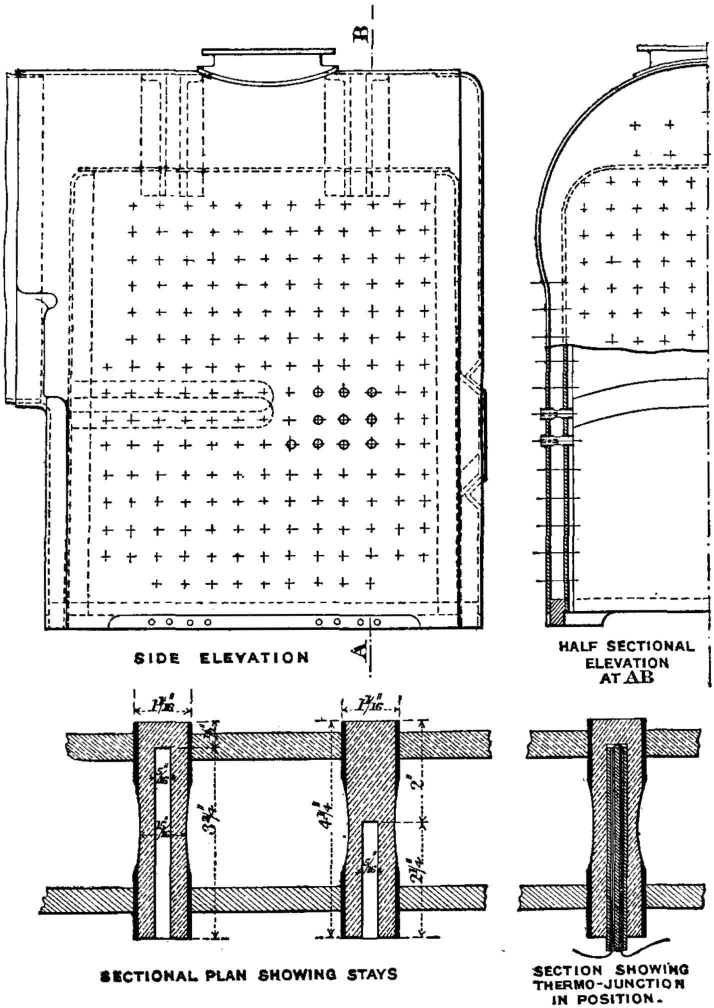
[2] Reports to the Alloys Research Committee, Inst. Mechanical Engineers.

[3] *Le Génie Civil*, vol. xix. p. 60. [4] *The Mechanical Engineer*, 1901, p. 200.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

motive type (boiler-pressure 120 lbs. per square inch) with seven stays made of the materials Nos. 1–5 (Appendix). Five of them had holes drilled down the centre to within ½ inch of the furnace end,

Figs. 10.



and two stays had holes drilled within 2 inches of the furnace end. They were all screwed ¼ inch through the copper plate (*Figs. 10*).

A portable electrical pyrometer, fitted with platinum and platinum-rhodium thermo-couple which could be read accurately

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

to 5° C., was employed for determining the temperature. The following Table gives the results recorded:—

Material of Stay.	Temperature.	
	Boiler steaming heavily and blowing off.	Boiler steaming lightly but blowing off.
Stay with hole drilled to within ½ inch of furnace end.		
No. 1. Copper rod	215° C. } (419° F.)	185° C. (365° F.)
„ 2. Copper-tin alloy	215° „ } (419° F.)	190° „ (374° „)
„ 3. Copper-zinc alloy	220° „ (428° „)	185° „ (365° „)
„ 4. Copper-aluminium alloy	230° „ (446° „)	190° „ (374° „)
„ 5. Mild steel (Bessemer) rod	215° „ (419° „)	185° „ (365° „)
Stay with hole drilled to within 2 inches of furnace end.		
No. 1.	170° C. (338° F.)	170° C. (338° F.)
„ 3.	175° „ (347° „)	165° „ (329° „)

The temperature of saturated steam at 120 lbs. per square inch is given as 350° F.

An attempt was also made to determine the temperature of the surface of the copper plate, and of the ends of the stays inside the fire-box, in the vicinity of the brick arch, by well insulating the thermo-couple, except the junction which was pressed against the plate or stay. The average of four tests gave a temperature of 540° C. (1,000° F.) for the surface of the copper plate, and 615° C. (1,140° F.) for the surface of the ends of the stays, which projected ¼ inch from the copper plate. From these figures it is fair to assume that in an express locomotive working at a pressure of 200 lbs. per square inch the temperature of the metal in similar positions would be higher, and that 600° F. at ½ inch from the stay-head would doubtless be reached.

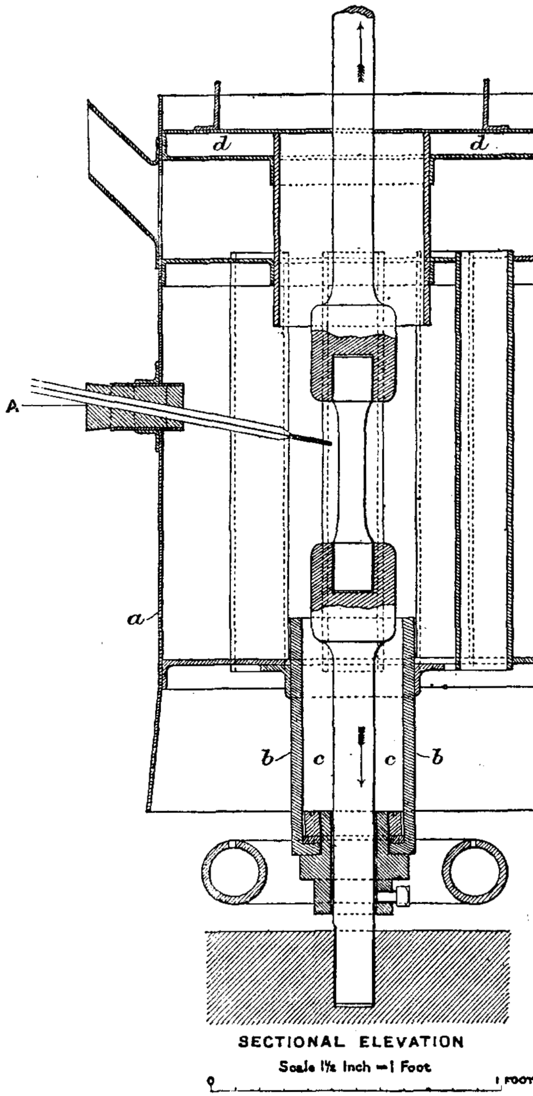
Tensile Tests.—As knowledge of the tensile strengths of the alloys already referred to was limited to temperatures below 400° F., a series of tests was made at the temperatures of 60°, 200°, 300°, 400°, 500°, 600°, 700°, and 750° F. The testing-machine used was a Buckton single-lever machine. The chemical analyses of the several materials tested are given in Tables I.–VI. in the Appendix. Three tests were made of each of Nos. 1–5. No. 6 was a specimen rod submitted, which sufficed for only one test at each temperature. All the test-pieces were 5 inches in length, and 0·564 inch in diameter; and the elongation was measured on a length of 2 inches. A specimen is shown in position in *Figs. 11* and *11a.*

When under preparation, all the test-pieces except the copper-

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

aluminium alloy were found to be highly uniform and homogeneous in structure. Pieces of the copper-aluminium alloy from the same

Fig. 11.



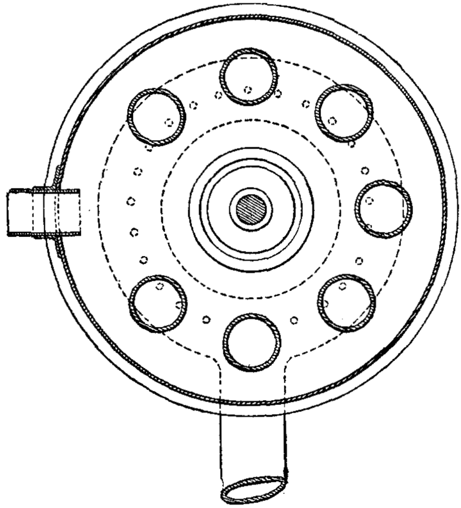
AIR-BATH FOR TENSILE TESTS AT HIGH TEMPERATURES.

rod varied in structure to the extent shown in Figs. 12, 13, and

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

14, which are magnified four diameters. It was also observed that the crystals were either large (Fig. 14) or small (Fig. 12), or large and small mixed (Fig. 13), but not of intermediate size. In view of this heterogeneous structure, the three test-pieces of the copper-aluminium alloy for each temperature consisted of one piece of all large crystals, marked "L"; one piece of all small crystals, marked "S"; and one piece, as nearly like *Fig. 13* as possible, marked "M." Separate chemical analyses of large-crystal and small-crystal test-pieces showed them to contain the same percentage of aluminium (7·13 per cent.).

Fig. 11a.



SECTIONAL PLAN ON A.A.

AIR-BATH FOR TENSILE TESTS AT HIGH TEMPERATURES.

Arrangements for Heating Test-pieces.—For the temperatures of 700° and 750° F., an air-bath was used, which is shown in *Figs. 11* and *11a.* It consists of a copper cylinder, in which are fitted seven 1-inch copper tubes; and the whole is carried on the bottom holder of the testing-machine by a nut and set screw. The outside of the bath (*a*) was covered by two sheets of asbestos, as was also the supporting tube (*b*). The spaces (*c*) and (*d*) were packed with asbestos wool. The bath was heated by a ring bunsen burner. For the temperatures 200° F. to 600° F. inclusive, an oil-bath, which has been described[1] by Mr. John A. F. Aspinall,

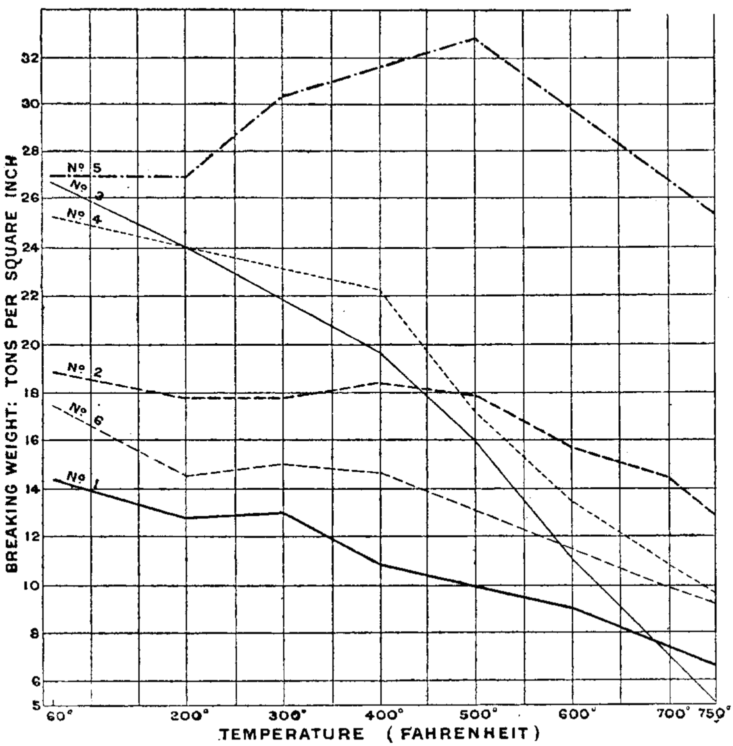
[1] Second Report to the Alloys Research Committee, Inst. Mechanical Engineers. Proceedings, 1893, p. 102.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

M. Inst. C.E., was used. The temperature was indicated by a mercurial thermometer.

Details of Tests.—Each test-piece was kept at the required temperature for 30 minutes before the first application of load; and the load was then applied at such a rate that fracture occurred in about 15 minutes, the recorded temperature never varying more than 10° F. during the test.

Fig. 15.



TENSILE STRENGTH OF FIRE-BOX STAYS BETWEEN 60° F. AND 750° F.

The results of the tests are given in Tables I.–VII., and the mean results are shown graphically in *Figs. 15* and *15a*. *Fig. 16* shows the variation in strength of the large- and small-crystal test-pieces of copper-aluminium alloy.

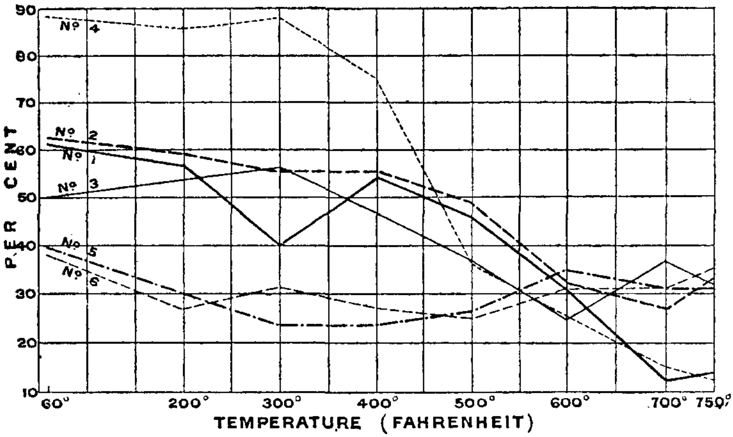
General Remarks on the Tensile Tests.—The uniformity of the rods tested—except copper-aluminium, Table IV.—is shown by the closeness of the results at the various temperatures. Through

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

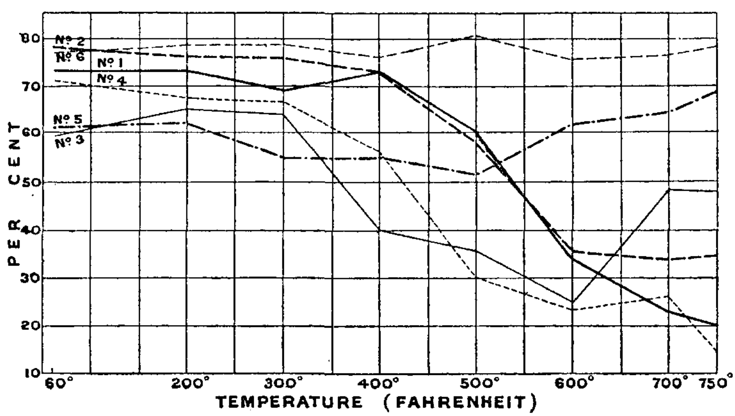
the whole range of tests, the fractures of the steel and of the special rolled copper are characteristic of ductile metals.

The fractures of the copper and of the copper-tin alloy at 600° F.

Figs. 15a.



Elongation on a Length of 2 inches.



Contraction of Area.

Ductility of Fire-Box Stays between 60° F. and 750° F.

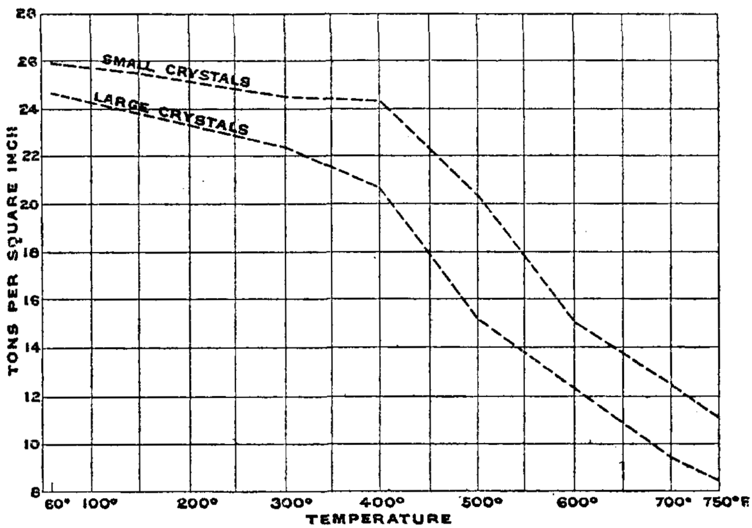
and upwards have distinctly a cast appearance; and copper-zinc and copper-aluminium alloys have a similar appearance at 500° F. and upwards. The special rolled copper rod (No. 6) behaved most satisfactorily, its contraction of area and elongation at all temperatures being very uniform. It is worthy of further consideration.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

The Copper-Aluminium Alloy.—The great variation in structure of this alloy is strikingly shown throughout the tensile tests. Below 400° F., all tests "L" show distinct crinkling on the extended length; tests "S" show practically none; while tests "M" invariably show distinct crinkling down two opposite sides (Fig. 17, Plate 4), but practically none down the other two (Fig. 18). Fig. 19 is an end view of this stay, and shows that where the crinkling is greatest the crystals are largest.

While the tests at 400° F. and higher temperatures were in

Fig. 16.



Variation in Strength of Rolled Copper-Aluminium Alloy (7·1 per Cent. Aluminium) between 60° F. and 750° F.

progress, a sharp grating noise was heard when the test-piece was extending, which increased in distinctness at the higher temperatures. On examining the specimens after fracture, a number of transverse cracks, varying in size, were observed. Photographs of portions of test-pieces "L" and "S" at temperatures of 400° and 500° F. are given in Figs. 20–23, Plate 4. This noise was evidently caused by sudden development of the cracks, due undoubtedly to the want of ductility at high temperatures.

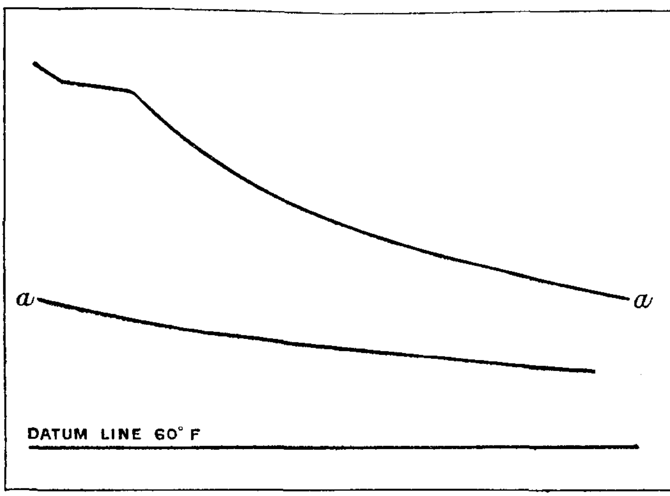
Mr. Charpy and Sir William Roberts-Austen have shown[1] that

[1] Fourth Report to the Alloys Research Committee, Inst. Mechanical Engineers. Proceedings, 1897, p. 39.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

the weakening effect of heat on certain brasses is due to the presence of a portion (a eutectic) melting at a low temperature. This point naturally received consideration. A cooling-curve (*Fig. 24*) was determined, but no second break was revealed, and consequently the curve throws no light on the subject. Further, as the alloy contains no injurious elements, it would appear that its weakness at temperatures above 400° F. is due to want of cohesion between the faces of the crystals of which it is composed. Large crystals will develop if a small-crystal specimen be exposed for a short time to a temperature below red heat (Figs. 25 and 26, Plate 5).

Fig. 24.



COOLING-CURVE OF COPPER-ALUMINIUM ROLLED ROD FROM THE SOLIDIFYING POINT (ABOUT 1,900° F.) TO 482° F.

Riveting Copper and Copper Alloys, etc., in Copper Plates.—On examining the leaky stays of the copper-zinc alloy, which during their life had been drilled and drifted, it was not possible to say whether the cracks at the bases of the threads were caused by the original riveting or by the subsequent drifting. With a view to ascertain the effect due to riveting alone, stays of each kind of metal, Nos. 1, 3, 4 and 5, were prepared in the ordinary way and were riveted into a piece of copper fire-box plate. They were then cut from the plate with the copper surrounding the threads, sectioned longitudinally, polished and etched (Figs. 27–30, Plate 5). It will be observed that the copper stay is the

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

only one of the four that has made a really good joint; each of the others distinctly shows imperfect contact between the threads of the stay and the plate. In fact, when the specimens were cut in two, the copper plate fell away from three specimens (Figs. 28–30), but remained fast in the other (Fig. 27). The riveting did not produce any marked change in the structure of the alloys.

These tests show that, except in the copper stay, the effect of riveting has been to expand the hole in the copper plate at the base, and also to damage the plate under the riveted head. Seeing, however, that the above results had not been obtained in actual practice, further specimens of Nos. 1, 2, 3, 4 and 5 were prepared, screwed into position in a fire-box, and riveted up in both plates: all done exactly in accordance with the Author's usual practice. They were cut out, with the copper or steel plate surrounding the threads, and were sectioned longitudinally, polished and etched (Figs. 31–35, Plate 5). The results undoubtedly point in the same direction as the preliminary tests, although the copper stay in Fig. 31 is not nearly as good a fit as that in Fig. 27: it is certainly, however, the best result of this series. Fig. 36 shows a bad joint made by using a stay with defective threads. Fig. 37 shows a joint made by the copper-zinc alloy in the steel plate.

It is evident from these riveting tests that the relative hardness of each stay, compared with the copper plate and the copper box into which it is riveted, is of great importance. With reference to the copper stays and fire-box plate, chemical analysis showed the hardening element to be arsenic, of which the quantity present in each case was as follows:—

Preliminary Tests—

Copper plate . .	0·55 per cent. of arsenic	Joint excellent. (Fig. 27.)
„ stay . .	0·34 „ „ „	

Practical Tests—

Copper plate (from fire-box.) . .	0·21 per cent. of arsenic	Joint not so good as above. (Fig. 31.)
Copper stay . .	0·26 „ „ „	

These figures account for the different riveting results obtained with copper.

In order to compare the relative hardness of the material used in these tests, recourse was had to the indentation test for hardness, devised by Professor W. C. Unwin, F.R.S.[1] Three tests were made with each specimen. The load, P, and the depth of

---

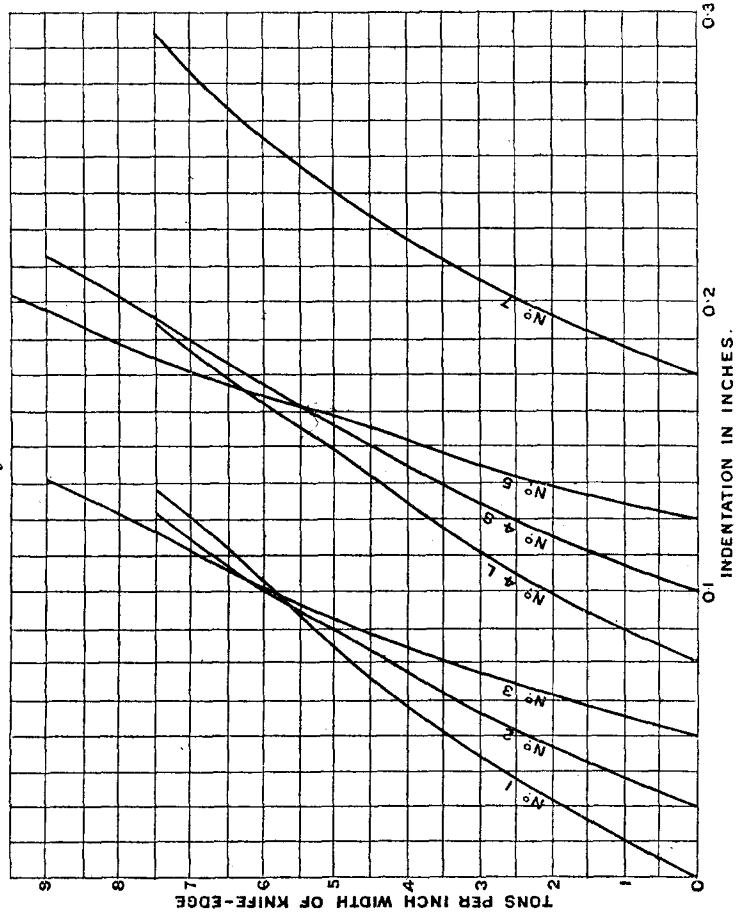
[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 334.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

indentation, i, are shown in *Fig 38;* and the hardness-number, C, is calculated according to the formula:—

$$C = \frac{P^{1\cdot 2}}{i}.$$

Fig. 38.



INDENTATION TESTS FOR HARDNESS.

The Table on page 105 gives the mean hardness-number of the three tests.

Figs. 39 and 40, Plate 5, show the hardness test-pieces of copper-aluminium alloy. It will be observed that the effect of the pressure has been to force the crystals out at the side of the test-piece, this being very marked in Fig. 40.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

The "hardness-number," therefore, together with the results of the riveting-tests, shows clearly that the riveting of a hard stay into a comparatively soft copper plate is the cause of the enlargment of the hole, and the consequent formation of an unsatisfactory joint; and this is, in all probability, the cause of the initial leaking of the stays made of the copper-zinc alloy. Further, in these experiments it has been noticed repeatedly that the effect of screwing a hard stay into a copper plate is to cut away part of the copper threads, leaving them thin.

Reference No. on Diagram. (Fig. 38.)	Particulars of Specimen.	Width of Specimen.	Mean Hardness-Number.
		Inch.	
1	Copper, rolled rod	0·483	84·8
2	Copper-tin alloy, rolled rod	0·494	110·0
3	Copper-zinc ,, ,, ,, ...	0·494	166·5
4 L	Copper-aluminium alloy, rolled rod, large crystals	0·494	93·2[1]
4 S	,, ,, ,, ,, ,, small ,, .	0·482	120·4[1]
5	Mild steel (Bessemer) ,, ,, ...	0·483	197·3
7	Arsenical copper, rolled plate	0·482	109·7

Fig. 41 is a section of a copper stay—selected at random—cut from a fire-box after 7 years' service; and although the head is much wasted, the joint is very good. Fig. 42 is a steel stay from the same fire-box after 12 years' service; the threads are almost corroded away, and their holding power must have been practically nil, the space between the threads being filled with corroded metal and boiler-scale, which were responsible for the joint. Fig. 43 is a copper stay from another boiler, cut from both plates after 8 years' service; although the joint is not as good as that shown in Fig. 41, it is satisfactory.

In conclusion, the Author thinks it will be agreed from this investigation that great tensile strength and ductility combined are not by any means the most important factors to be considered when selecting a material for stays in locomotive copper fire-boxes; but that, whatever the composition of the stay may be, it should be softer than the copper fire-box plate into which it is riveted.

The Paper is accompanied by forty-two diagrams and photographs, from which Plates 4 and 5 and the Figures in the text have been prepared.

[1] In the riveting-tests small-crystal stays were used.

[ADDENDUM.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

ADDENDUM.

Note on the Wastage of a Muntz-Metal Stud Exposed to Bilge-Water.

A Muntz-metal stud taken from the valve-chamber of a bilge donkey-pump on a Fleetwood and Belfast steamer, belonging to the Lancashire & Yorkshire and London & North Western Railway Companies, owing to the development of a flaw, showed, when broken through the flaw, an inner brassy core, while the outer portion was distinctly porous and coppery in appearance. When in position the stud and the brass seats to which it was secured were subject to the same action of sea- and harbour-water. The upper portion of the stud just above the flaw was also subject to the continual lifting and jarring of a small brass valve.

When sectioned longitudinally, polished and etched, the stud revealed the remarkable structure shown in Fig. 44, Plate 6, which is a full-size view of the stud (in three pieces). Fig. 45 is a transverse section of the stud at X X magnified four diameters. The light parts of the photograph (Fig. 44), marked "L," are the colour of ordinary brass, and are evidently portions of the original metal; whereas the dark parts, marked "D," are somewhat porous and coppery in appearance.

Chemical analyses of portions taken from the stud at the parts marked A, A1, B, C, and C1 gave the following results:—

Metal.	Sample taken from		Sample taken from B.	Sample taken from	
	A Centre Core.	A 1 Outside Portion.		C Centre Portion.	C 1 Outside Portion.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Copper	62·63	65·51	66·74	66·69	66·61
Zinc	37·09	33·10	32·42	32·44	32·85
Lead	0·56	0·66	0·51	0·51	0·51
Total	100·28	99·27	99·67	99·64	99·97
	Taking the Copper as 100 in each sample, the Zinc varies as follows:—				
Copper	100	100	100	100	100
Zinc	59	51	49	49	49

From the analyses it is evident that the stud has lost zinc, owing most probably to the solvent action of the salt water; which of course accounts for its wastage.

The Note is accompanied by two photographs, from which Plate 6 has been prepared.

[Appendix.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

APPENDIX.

TABLE I.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 1.

	Per Cent.
Copper	99·76
Arsenic	0·20
Nickel	0·04
Sulphur	0·01
Phosphorus	0·01
Lead, Iron, Antimony	Traces
	100·02

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	14·32	71·7	62	Normal rolled-copper-rod fracture.
b	,,	14·28	73·6	60	
c	,,	14·32	71·7	61	
2 *a*	200	12·72	73·6	54	Ditto.
b	,,	12·64	73·6	57	
c	,,	12·76	73·6	57	
3 *a*	300	13·08	69·8	40	Ditto.
b	,,	12·92	69·8	40	
c	,,	13·04	69·8	40	
4 *a*	400	10·80	75·4	54	Ditto.
b	,,	10·76	71·7	53	
c	,,	10·84	71·7	55	
5 *a*	500	9·88	61·5	48	Inferior rolled-copper-rod fracture.
b	,,	9·80	57·0	46	
c	,,	9·92	61·5	46	
6 *a*	600	8·59	35·9	36	Cast-copper fracture.
b	,,	8·75	36·1	33	
c	,,	9·76	27·3	23	
7 *a*	700	7·40	27·6	13	Ditto.
b	,,	7·40	15·0	10	
c	,,	7·32	27·6	13	
8 *a*	750	6·48	18·3	14	Ditto.
b	,,	6·64	21·5	15	
c	,,	6·40	21·5	12	

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

TABLE II.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER-TIN ALLOY ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 2.

	Per Cent.
Copper	97·07
Tin	2·91
Phosphorus	0·02
	100·00

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	19·00	77·1	65	Normal rolled-copper-rod fracture.
b	,,	18·99	78·6	64	
c	,,	18·72	78·1	61	
2 *a*	200	17·93	75·5	58	Ditto.
b	,,	17·98	78·6	59	
c	,,	17·81	75·5	58	
3 *a*	300	17·64	75·4	58	Ditto.
b	,,	18·29	77·2	58	
c	,,	17·73	75·5	54	
4 *a*	400	18·35	73·5	56	Ditto.
b	,,	18·12	71·7	53	
c	,,	18·48	73·6	57	
5 *a*	500	17·88	52·2	48	Inferior rolled-copper-rod fracture.
b	,,	17·86	61·2	48	
c	,,	18·02	59·6	51	
6 *a*	600	15·80	36·4	32	Cast-copper fracture.
b	,,	16·04	36·4	32	
c	,,	15·52	33·5	31	
7 *a*	700	14·48	36·9	30	Ditto.
b	,,	14·62	36·1	30	
c	,,	13·80	30·6	24	
8 *a*	750	12·68	38·2	33	Ditto.
b	,,	12·73	33·3	34	
c	,,	12·68	33·5	34	

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

TABLE III.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER-ZINC ALLOY ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 3.

	Per Cent.
Copper	60·23
Zinc	39·61
Iron	0·28
Manganese	0·03
Arsenic	0·10
Antimony	0·01
Lead and Phosphorus	Traces
	100·26

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons. per Sq. In.	Per Cent.	Per Cent.	
a	60	26·60	61·5	50	Normal rolled-brass fracture.
b	,,	26·53	58·9	50	
c	,,	26·55	59·3	51	
2 *d*	200	24·04	61·5	53	Ditto.
e	,,	23·96	67·8	53	
f	,,	24·08	65·8	55	
3 *a*	300	21·63	65·9	58	Ditto.
b	,,	21·71	57·2	53	
c	,,	22·45	67·7	57	
4 *a*	400	19·59	48·5	52	Inferior rolled-brass fracture.
b	,,	19·72	36·4	41	
c	,,	19·52	36·4	45	
5 *a*	500	16·23	41·2	41	Cast-brass fracture.
b	,,	16·03	39·6	41	
c	,,	15·48	27·0	27	
6 *a*	600	11·68	21·4	24	Ditto.
b	,,	10·69	26·4	27	
c	,,	10·92	27·6	25	
7 *a*	700	7·08	47·2	32	Ditto.
b	,,	7·32	49·7	46	
c	,,	7·36	49·7	33	
8 *a*	750	5·16	49·7	34	Ditto.
b	,,	5·00	47·2	32	
c	,,	5·12	47·2	32	

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

TABLE IV.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER-ALUMINIUM ALLOY ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 4.

	Per Cent.
Copper	92·91
Aluminium	7·13
	100·04

Mark on Specimen.	Temperature of Tests. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
L	60	24·88	73·6	89	Normal rolled-bronze fracture.
M	,,	24·68	69·8	88	
S	,,	25·96	69·8	89	
2 L	200	23·32	65·8	81	Ditto.
M	,,	23·72	67·8	95	
S	,,	25·20	69·8	83	
3 L	300	22·28	67·8	95	Ditto.
M	,,	22·76	63·7	87	
S	,,	24·44	67·8	81	
4 L	400	20·64	54·6	74	Inferior rolled-bronze fracture.
M	,,	21·76	54·6	78	
S	,,	24·32	57·0	74	
5 L	500	15·12	30·6	39	Cast-brass fracture.
M	,,	15·68	27·6	31	
S	,,	20·40	33·5	38	
6 L	600	12·08	21·5	26	Ditto.
M	,,	13·56	27·6	29	
S	,,	14·92	21·5	22	
7 L	700	10·04	27·6	16	Ditto.
M	,,	9·32	27·6	16	
S	,,	12·56	21·8	14	
8 L	750	8·57	15·4	14	Ditto.
M	,,	9·20	15·0	14	
S	,,	11·04	11·8	10	

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

TABLE V.—CHEMICAL ANALYSIS AND TENSILE TESTS OF MILD STEEL (BESSEMER) ROLLED ROD, AS USED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 5.

	Per Cent.
Silicon	0·05
Carbon, combined	0·13
Sulphur	0·03
Phosphorus	0·07
Arsenic	0·04
Manganese	0·48
Iron (by difference)	99·20
	100·00

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	26·84	61·5	39	Normal mild-steel fracture.
b	„	26·96	61·5	40	
c	„	26·88	61·5	40	
2 *a*	200	25·92	63·7	31	Ditto.
b	„	25·84	61·5	28	
c	„	28·88	61·5	31	
3 *a*	300	30·20	52·2	22	Ditto.
b	„	29·52	54·6	23	
c	„	30·88	57·0	26	
4 *a*	400	31·65	54·3	24	Ditto.
b	„	31·92	54·6	24	
c	„	31·36	54·6	24	
5 *a*	500	33·16	52·2	26	Ditto.
b	„	32·60	52·2	26	
c	„	32·48	52·2	26	
6 *a*	600	29·80	61·4	34	Ditto.
b	„	30·16	61·5	34	
c	„	29·72	61·5	34	
7 *a*	700	26·76	65·8	31	Ditto.
b	„	26·64	65·8	32	
c	„	26·80	65·8	32	
8 *a*	750	25·36	67·8	31	Ditto.
b	„	25·28	69·8	32	
c	„	25·32	69·8	33	

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

TABLE VI.—CHEMICAL ANALYSIS AND TENSILE TESTS OF SPECIAL COPPER ROLLED ROD, SUBMITTED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 6.

	Per Cent.
Copper (by difference)	99·89
Arsenic	0·01
Nickel	0·02
Phosphorus	0·08
Iron	Traces
Sulphur	Traces
	100·00

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	17·48	77·1	38	Normal rolled-copper rod fracture.
2 *a*	200	14·48	78·9	27	Ditto.
3 *a*	300	15·16	78·8	31	Ditto.
4 *a*	400	14·52	77·1	27	Ditto.
5 *a*	500	13·12	80·4	25	Ditto.
6 *a*	600	11·52	75·4	31	Ditto.
7 *a*	700	9·92	75·4	33	Ditto.
7 *b*	700	9·96	78·6	32	Ditto.
8 *a*	750	9·24	78·8	36	Ditto.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

TABLE VII.—TENSILE TESTS AT ELEVATED TEMPERATURES.

Average Results.

Reference Number.	Number of Tests Made.	Temperature of Tests. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Reference Number.	Number of Tests Made.	Temperature of Tests. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.
		Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.			Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.
1	3	60	14·31	72·3	61·0	4	3	60	25·17	71·1	88·7
,,	,,	200	12·71	73·6	56·0	,,	,,	200	24·08	67·8	86·3
,,	,,	300	13·01	69·8	40·0	,,	,,	300	23·16	66·4	87·7
,,	,,	400	10·80	72·9	54·0	,,	,,	400	22·24	55·4	75·3
,,	,,	500	9·87	60·0	46·7	,,	,,	500	17·07	30·6	36·0
,,	,,	600	9·03	33·1	30·7	,,	,,	600	13·52	23·5	25·7
,,	,,	700	7·37	23·4	12·0	,,	,,	700	10·64	25·7	15·3
,,	,,	750	6·51	20·4	13·7	,,	,,	750	9·60	14·1	12·7
2	3	60	18·90	77·9	63·3	5	3	60	26·89	61·5	39·7
,,	,,	200	17·91	76·5	58·3	,,	,,	200	26·88	62·2	30·0
,,	,,	300	17·89	76·0	55·7	,,	,,	300	30·20	54·6	23·7
,,	,,	400	18·32	72·9	55·3	,,	,,	400	31·64	54·5	24·0
,,	,,	500	17·92	57·7	49·0	,,	,,	500	32·75	52·2	26·0
,,	,,	600	15·79	35·4	31·7	,,	,,	600	29·89	61·5	34·0
,,	,,	700	14·30	34·5	28·0	,,	,,	700	26·73	65·8	31·7
,,	,,	750	12·70	35·0	33·7	,,	,,	750	25·32	69·1	32·0
3	3	60	26·56	59·9	50·3	6	1	60	17·48	77·1	38·0
,,	,,	200	24·03	65·0	53·7	,,	,,	200	14·48	78·9	27·0
,,	,,	300	21·93	63·6	56·0	,,	,,	300	15·16	78·8	31·0
,,	,,	400	19·61	40·4	46·0	,,	,,	400	14·52	77·1	27·0
,,	,,	500	15·91	35·9	36·3	,,	,,	500	13·12	80·4	25·0
,,	,,	600	11·10	25·1	25·3	,,	,,	600	11·52	75·4	31·0
,,	,,	700	7·25	48·9	37·0	,,	2	700	9·94	77·0	32·5
,,	,,	750	5·09	48·0	32·7	,,	1	750	9·24	78·8	36·0

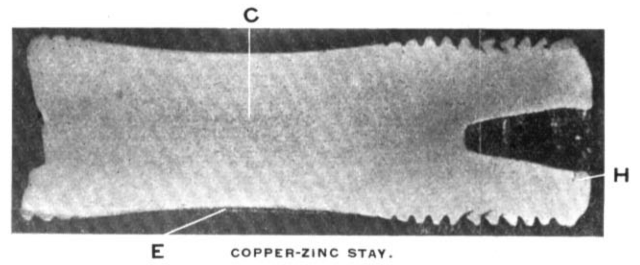
Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

LOCOMOTIVE FIRE-BOX STAYS.

MAGNIFICATION.
FIGS. 1, 2 & 5, ACTUAL SIZE.
FIGS. 3, 4, & 6-19, 4 DIAMETERS.
FIGS. 20-23, 2 DIAMETERS.

Figs. 1.

Fig. 2.



COPPER-ZINC STAY.

Fig. 3.

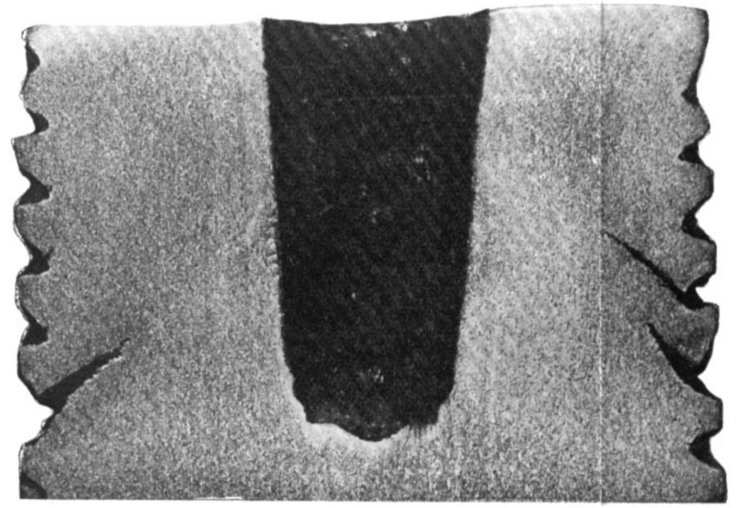
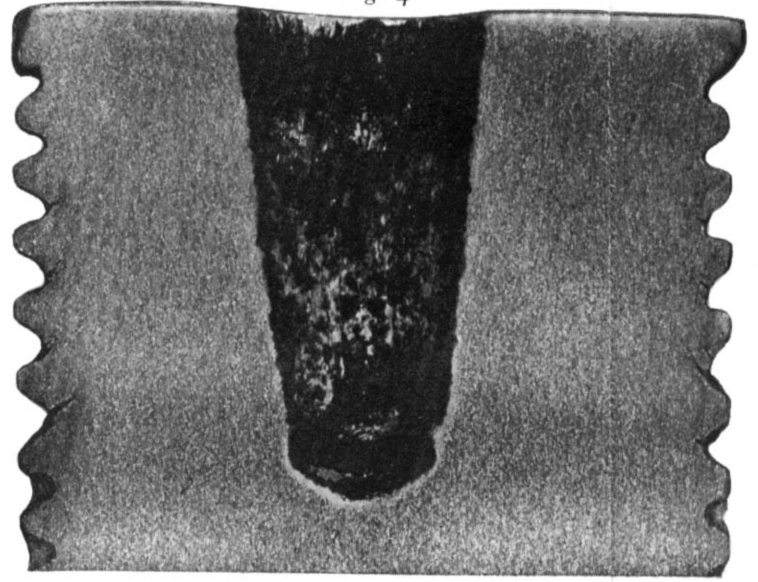
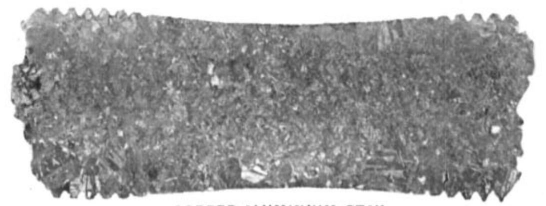


Fig. 4.



COPPER-ZINC STAYS AS TAKEN FROM FIRE-BOX.

Fig. 5.

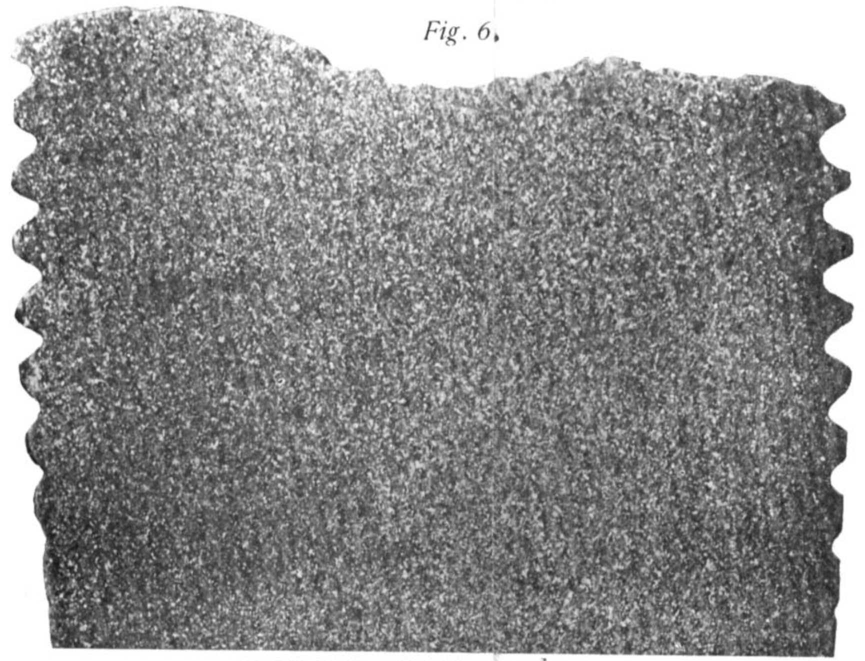


COPPER-ALUMINIUM STAY.

Fig. 9.

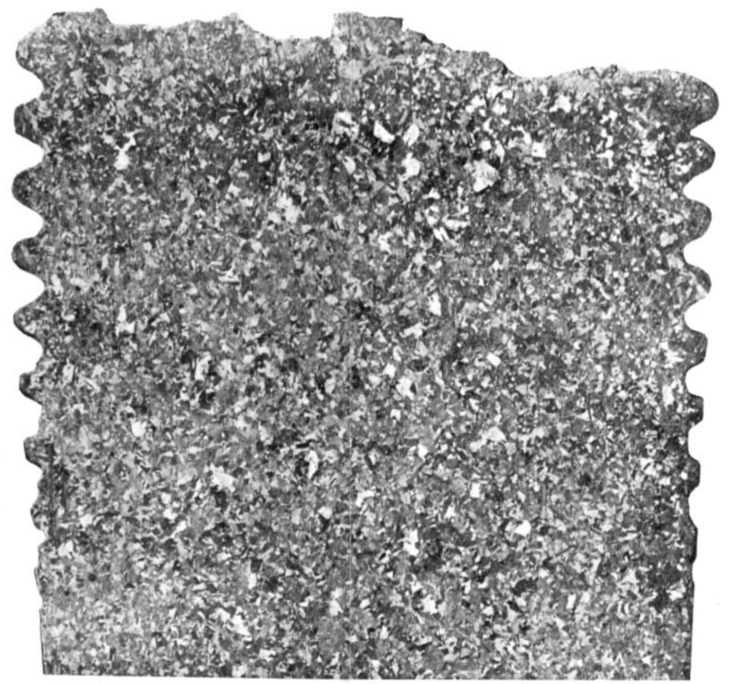
COPPER-ALUMINIUM STAY. BROKEN HEAD

Fig. 6.



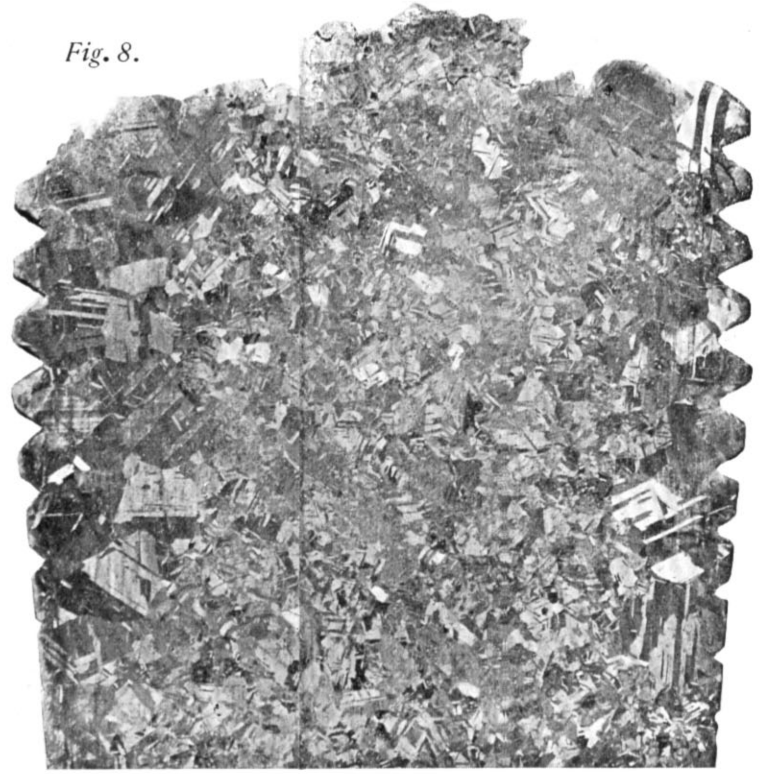
COPPER-ALUMINIUM STAY. SMALL CRYSTALS.

Fig. 7.



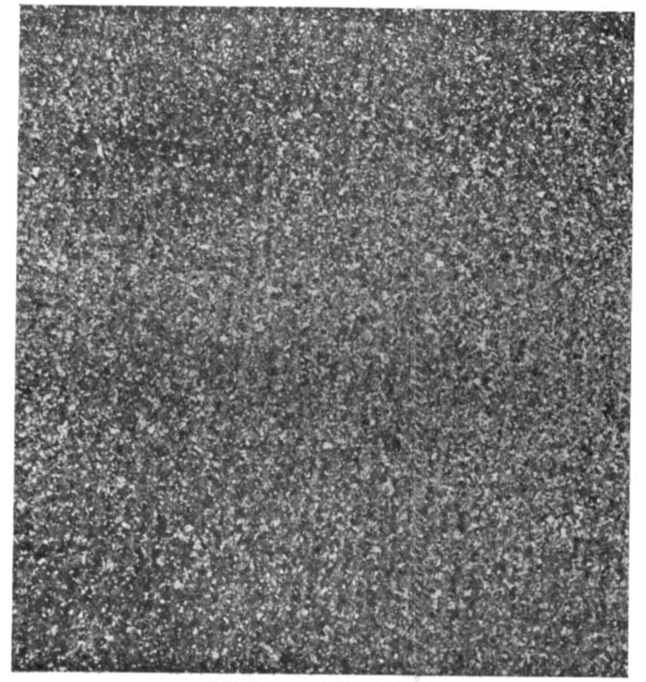
COPPER-ALUMINIUM STAY. RATHER LARGE CRYSTALS

Fig. 8.



COPPER-ALUMINIUM STAY. VERY LARGE CRYSTALS.

Fig. 12.



COPPER-ALUMINIUM ROLLED ROD. SMALL CRYSTALS.

Fig. 13.

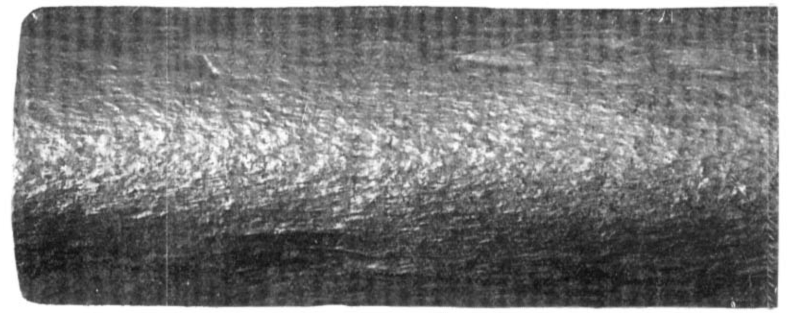
COPPER-ALUMINIUM ROD. MIXED CRYSTALS.

Fig. 14.

COPPER-ALUMINIUM ROD. LARGE CRYSTALS.

Fig. 17.

Fig. 18.



COPPER-ALUMINIUM ALLOY. ROLLED ROD.

Fig. 19.

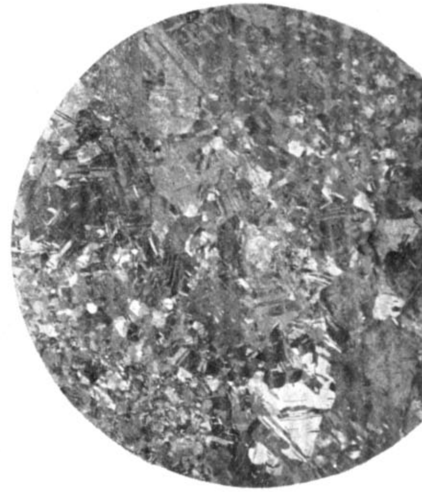


Fig. 20.

TEST "S" AT 400° F.

Fig. 21.

TEST "L" AT 400° F.

Fig. 22.

TEST "S" AT 500° F.

Fig. 23.

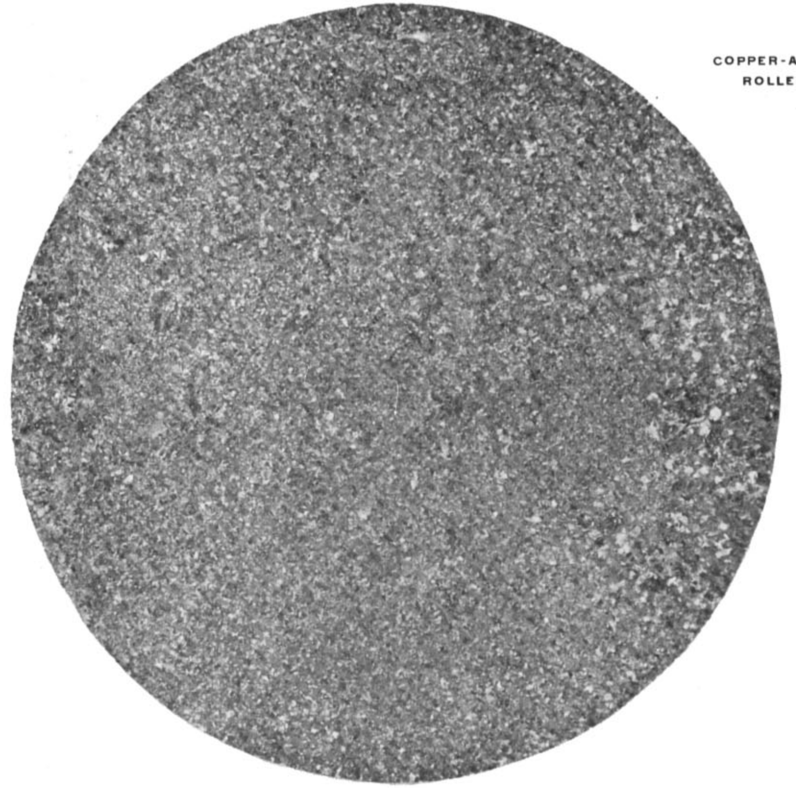
TEST "L" AT 500° F.

COPPER-ALUMINIUM ROLLED ROD.

F. W. WEBB.

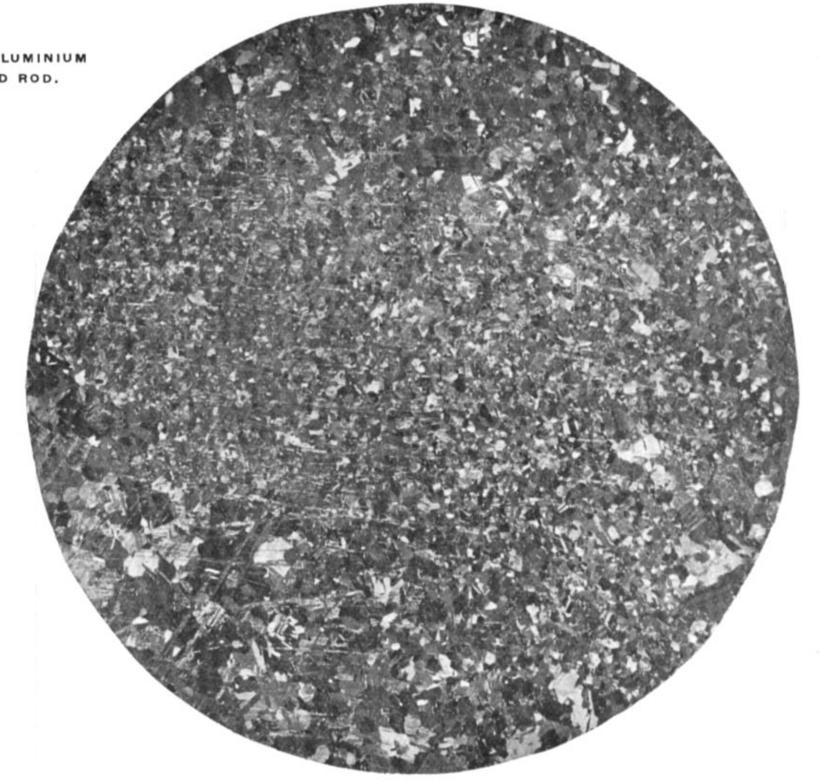
Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

Fig. 25.



BEFORE HEATING.

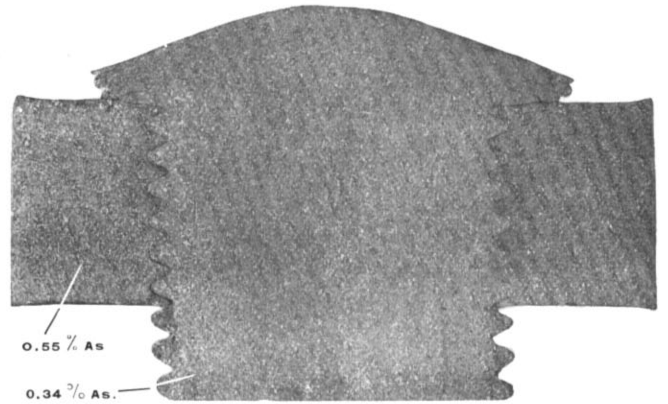
Fig. 26.



AFTER HEATING.

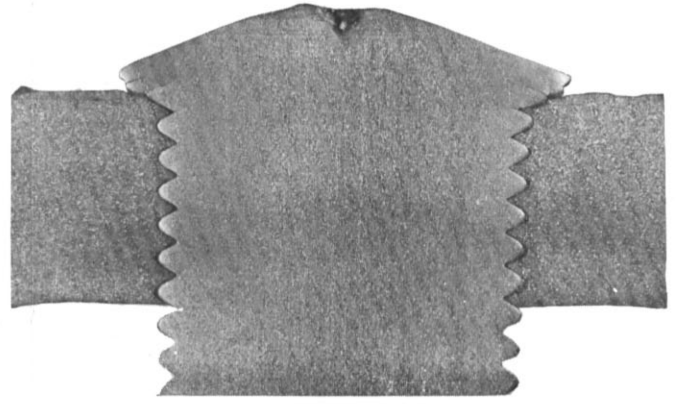
COPPER-ALUMINIUM ROLLED ROD.

Fig. 27.



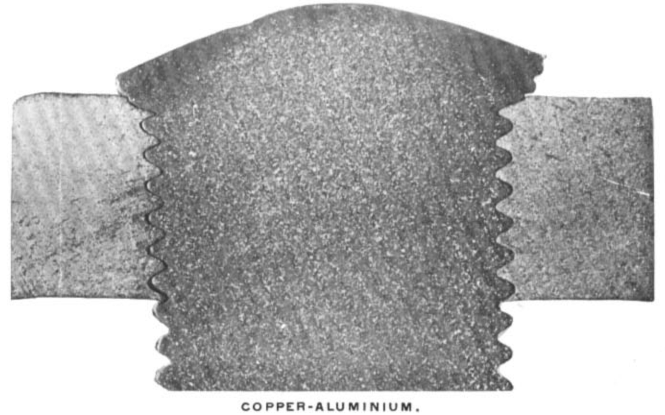
COPPER.

Fig. 28.



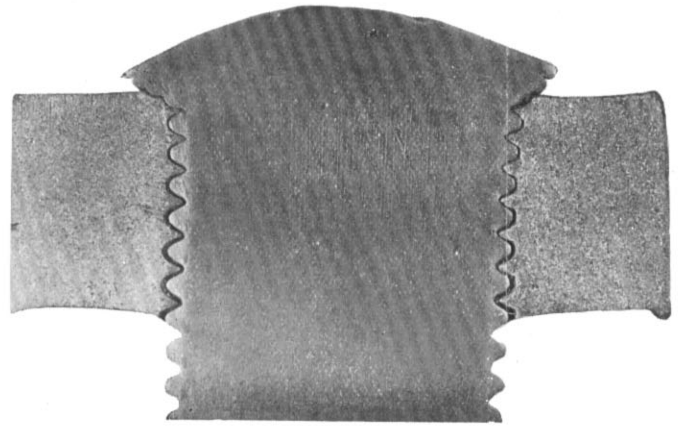
COPPER-ZINC.

Fig. 29.



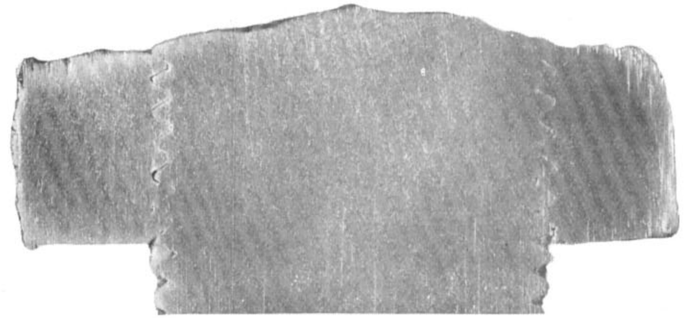
COPPER-ALUMINIUM.

Fig. 30.



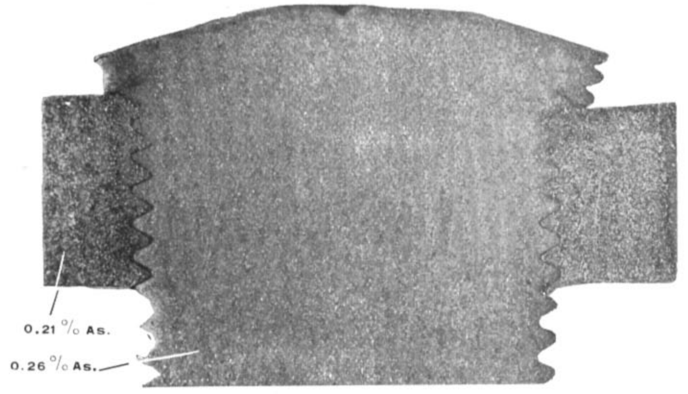
MILD STEEL.

Fig. 41.



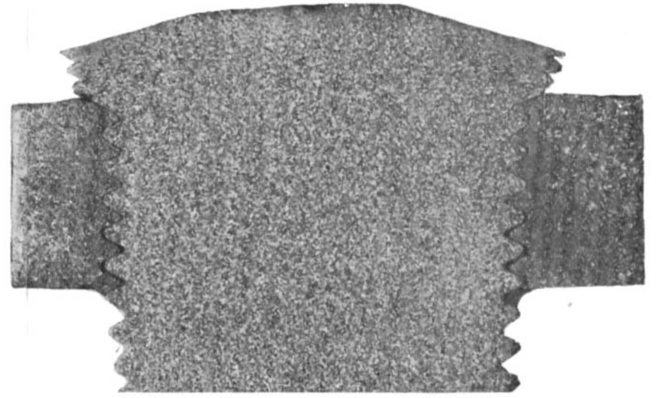
COPPER STAY IN COPPER FIRE-BOX AFTER 7 YEARS' SERVICE.

Fig. 31.



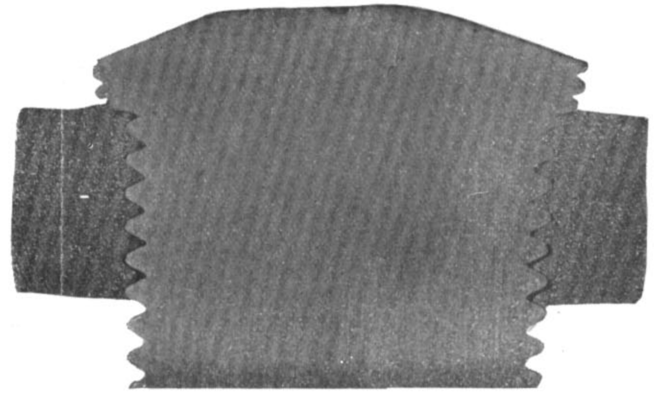
COPPER

Fig. 32.



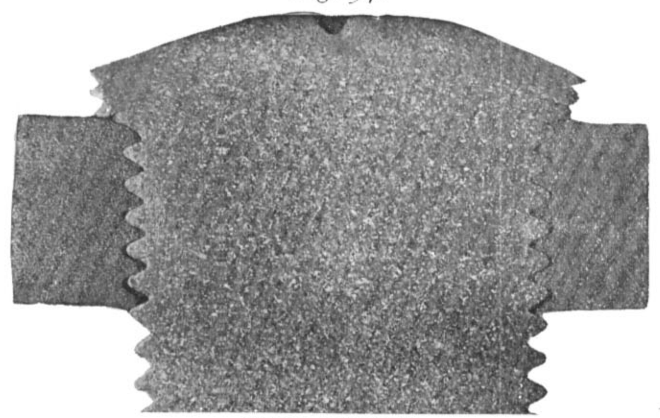
COPPER-TIN.

Fig. 33.



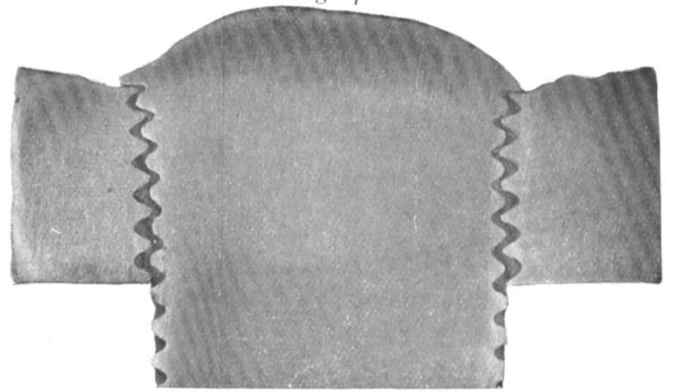
COPPER-ZINC.

Fig. 34.



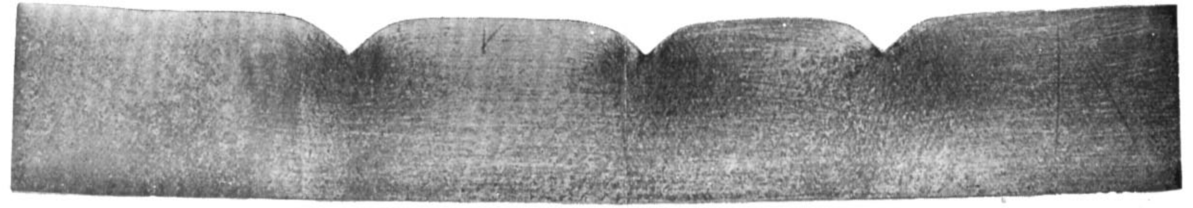
COPPER-ALUMINIUM.

Fig. 42.



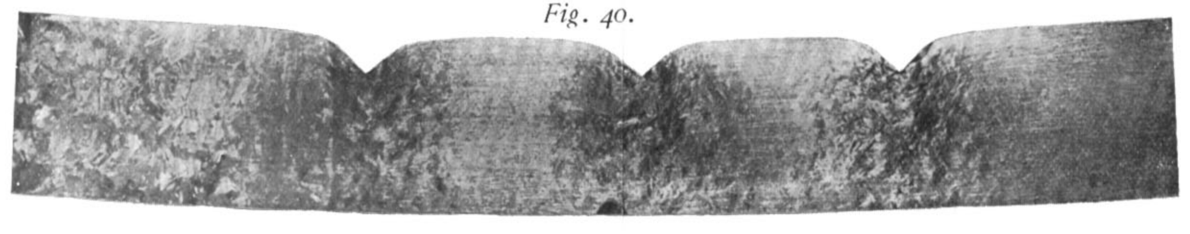
STEEL STAY IN COPPER FIRE-BOX AFTER 12 YEARS' SERVICE.

Fig. 39.



SMALL CRYSTALS.

Fig. 40.

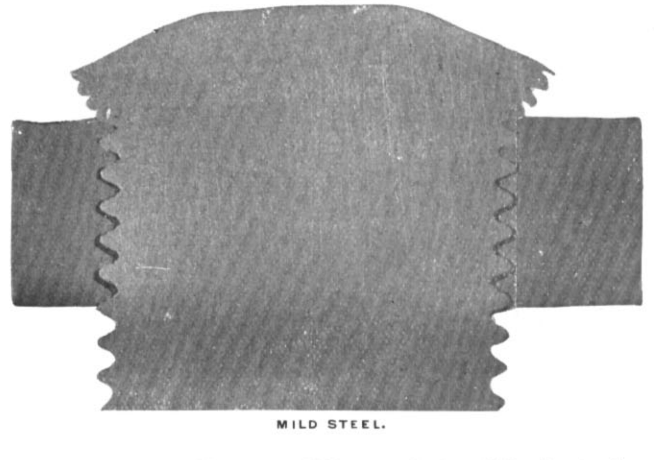


LARGE CRYSTALS.

COPPER-ALUMINIUM ALLOY, ROLLED ROD. INDENTATION TEST PIECES.

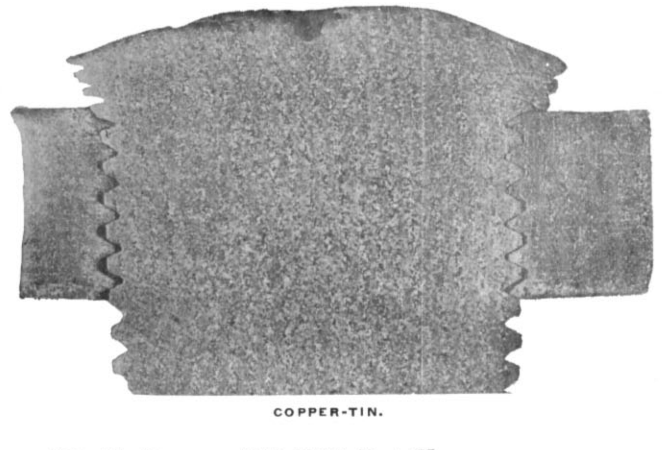
MAGNIFICATION.
FIGS. 25, 26, 39 AND 40, 4 DIAMETERS.
FIGS. 27-37, 41 AND 42, 2 DIAMETERS.

Fig. 35.



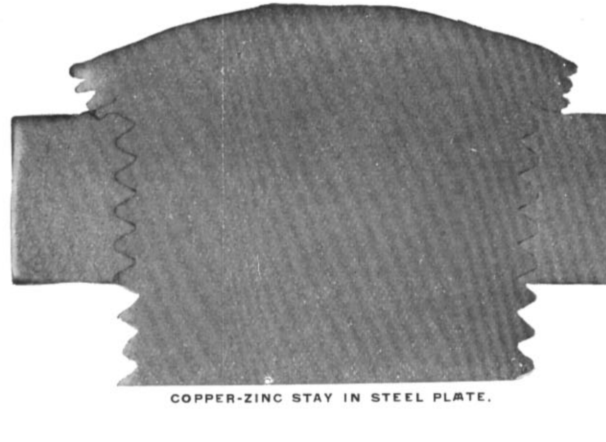
MILD STEEL.

Fig. 36.



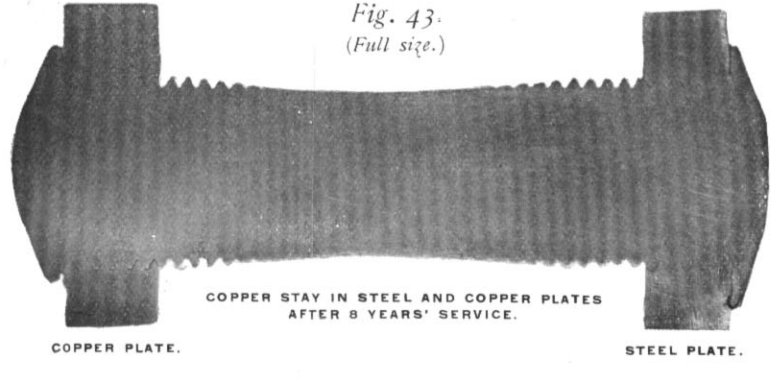
COPPER-TIN.

Fig. 37.



COPPER-ZINC STAY IN STEEL PLATE.

Fig. 43. (*Full size.*)



F. W. WEBB.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reserved.

WASTAGE OF A MUNTZ-METAL STUD.

Fig. 44 —(*Full size.*)

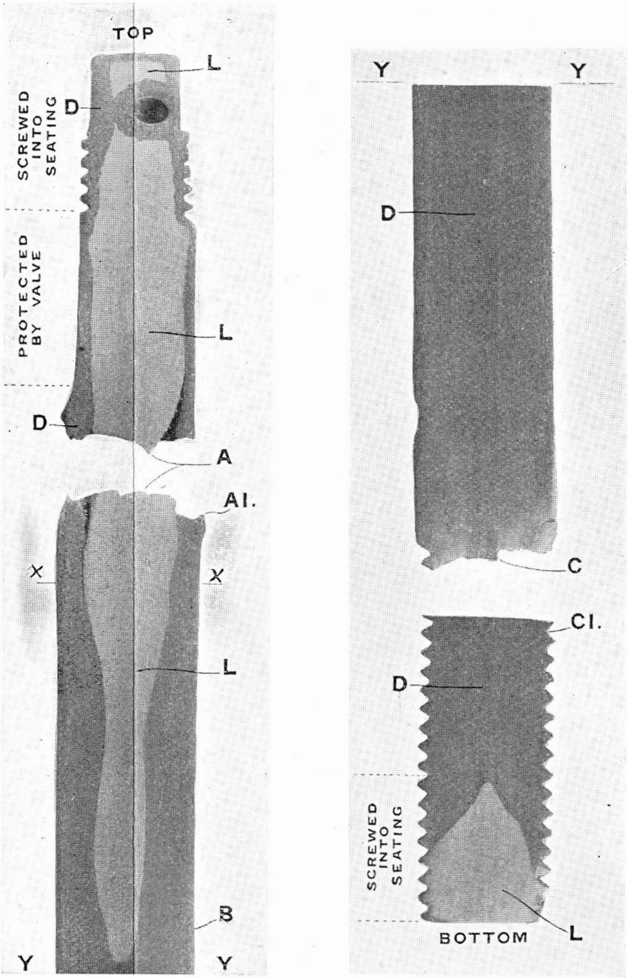
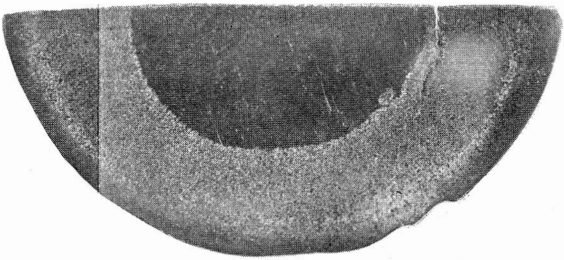


Fig. 45.



CROSS SECTION AT XX. MAGNIFIED 4 DIAMETERS.

Downloaded by [University of Sussex] on [18/09/16]. Copyright © ICE Publishing, all rights reser